Lifetime measurements in ^{91}Zr

P. Dey[1],* R. Palit[1], F. S. Babra[1], Biswajit Das[1], S. V. Jadhav[1], A. Kundu[1], Md. S. R. Laskar[1], V. Malik[1], B. S. Naidu[1], D. Negi[1], and A. T. Vazhappilly[1]
[1]*Department of Nuclear and Atomic Physics, Tata Institute of Fundamental Research, Mumbai - 400005, INDIA*

Introduction

Excited states in atomic nuclei can be generated by two extreme modes of excitations connected to the single-particle and collective degrees of freedom [1]. Nuclei around closed-shell mainly show particle-hole excitation across the shell gap. Due to the spherical ground state of even-even Zr isotopes around $A \sim 90$, with $Z = 40$ semimagic proton number, quadrupole collectivity is seen to be less compared to the neighbouring nuclei [2]. In contrast, large octupole collectivity has been observed through the measurement of enhanced $E3$ transition probability, $B(E3)$ [3]. The principal feature of these low-energy excitations is the association with nuclear shapes that break reflection symmetry.

In the neighbouring odd-A nuclei having one particle outside the even-even core, the coupling of a valence particle with an octupole phonon can induce octupole collectivity by acquiring a permanent octupole deformation [4]. The particle-octupole-phonon model favors strong coupling between the orbitals $j_1 = l_1 \pm 1/2$ and $j_2 = l_2 \pm 1/2$, if, $| j_1 - j_2 | = | l_1 - l_2 | = 3$. This phenomenon has been observed throughout the whole nuclear chart. Among the Zr isotopes, ^{91}Zr remains a good candidate to probe the $B(E3)$ where one valence neutron can be predicted to couple with an octupole phonon.

Experimental details and Data analysis

Excited states of ^{91}Zr were populated using heavy-ion fusion-evaporation reactions with a 60 MeV ^{13}C beam provided by the TIFR-BARC Pelletron Linac Facility (PLF) at TIFR, Mumbai. The target used was 1 mg/cm^2 thick ^{82}Se with a backing of ^{197}Au foil of thickness 4.3 mg/cm^2. A hybrid array consisting of 16 Compton-suppressed clover HPGe detectors arranged in spherical geometry and 14 $LaBr_3$(Ce) detectors coupled with digital data acquisition system was used for the experiment. Synchronization method between two crates containing one crate for digitizer with 100-MHz sampling frequency for HPGe and other for digitizer with 250-MHz sampling frequency for $LaBr_3$(Ce) detectors, was implemented. The data were sorted using MARCOS and RADWARE packages.

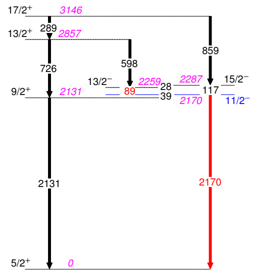

FIG. 1: Partial level scheme of ^{91}Zr showing the relevant states and γ-transitions.

The partial level scheme of ^{91}Zr, resulting from the present analysis, is presented in FIG. 1. The proposed $11/2^-$ level at $E_x = 2170$ keV is deexcited by the emission of 39- and 2170-keV γ-rays. The energy gate of 859-keV from the HPGe clover detectors has been used to select the cascade of γ-rays across the 2170 keV state in $LaBr_3$(Ce) to get the time spectrum. FIG. 3 shows $LaBr_3$ energy spectrum obtained with 859-keV gate. The decay half-life for the $11/2^-$ state was extracted using time difference spectrum between 2170- and 89-keV γ-transitions. Four conditional time spectra were generated by putting energy gate around

*Electronic address: piku.dey@tifr.res.in

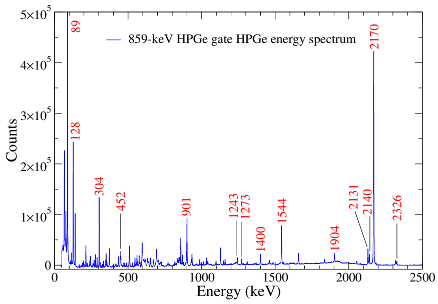

FIG. 2: Energy spectrum obtained in clover HPGe detectors by putting 859-keV energy on gate HPGe detector. Transitions marked in red belong to ^{91}Zr.

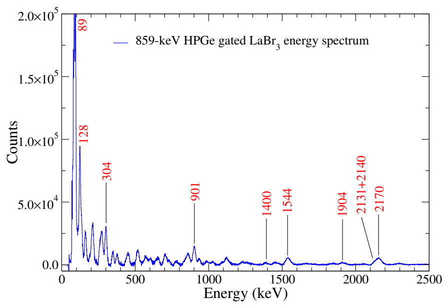

FIG. 3: Energy spectrum obtained in LaBr$_3$(Ce) detectors by putting 859-keV energy on gate HPGe detector. Transitions marked in red belong to ^{91}Zr.

the peaks and backgrounds of the these two transitions. The final time difference spectrum was generated by,

$$T = T_{p1,p2} - T_{p1,b2} - T_{b1,p2} + T_{b1,b2}. \quad (1)$$

The time difference spectrum was fitted with a convolution function associated with an exponential decay defined by mean-lifetime (τ) and a Gaussian prompt-response function defined by standard deviation (σ) as follows,

$$I(t) = A\,\exp\Big(\frac{\sigma^2}{2\tau^2} - \frac{1}{\tau}\Big)\Big[1 - \mathrm{erf}\Big(\frac{\sigma^2 - \tau t}{\sqrt{2}\sigma\tau}\Big)\Big], \quad (2)$$

where erf() corresponds to the error function, A is an intensity normalization constant, and t is the time difference since the defined time zero. The fitting procedure is similar to what has been mentioned in Ref. [5].

Results and Discussions

By fitting the time spectrum between 2170- and 89-keV with Eq. (2), the preliminary value half-life of the $11/2^-$ state has been found to be $t_{1/2}^{\mathrm{expt}} = 546 \pm 42$ ps. Since the low energy 39-keV transition decaying from the 2170 keV state has not been observed in this experiment, the branching ratio of 2170-keV transition, $R_B = 0.936$ was taken from NNDC [6] for calculating partial half-life, $t_{1/2}^{\mathrm{partial}}$.

$$B(E3) = \frac{1.75 \times 10^{-3} \times \ln(2)}{t_{1/2}^{\mathrm{partial}} E_\gamma^7}\; e^2\mathrm{fm}^6, \quad (3)$$

where E_γ is given in MeV unit. The reduced transition probability using Eq. (3), is obtained as $B(E3; 11/2^- \rightarrow 5/2^+) = 18.7 \pm 1.4$ W.u. Comparison of $B(E3)$ strength with neighbouring isotopes will be presented to understand the evolution of collectivity in this mass region.

Acknowledgments

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